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Title: DARHT Radiographic Analysis of Spatially Modulated Objects

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DARHT Radiographic Analysis of Spatially Modulated Objects

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This document describes some analysis methods that can be performed using the Kaleidoscope test object (KTO) in order to assess DARHT radiography performance. The goal of these methods is to provide a simple metric of radiographic performance to compare different system configurations at DARHT. Specifically, these methods can be used to assess the Tiffany configurations to determine relative radiographic performance. To demonstrate the methods, we show results analysis performed on the 'Tiffany A' shot conducted in July 2021.

KTO description

Two types of features exist within the KTO: (1) an outer ring comprising circular depressions of equal diameter and varying depth, called "circles", and (2) two inner rings of slit patterns with varying spatial frequency and either three or five periods, called "slits". A DARHT radiograph of the entire object is shown in Figure 1. The KTO is 16.2 mm thick, and the circles are 9 mm in diameter, with depth ranging from 0.1 to 4.0 mm. The slits are rectangular through-cuts, 1.5cm in length and with feature width equal to the spacing and ranging from 0.124 to 3.99 mm[1].

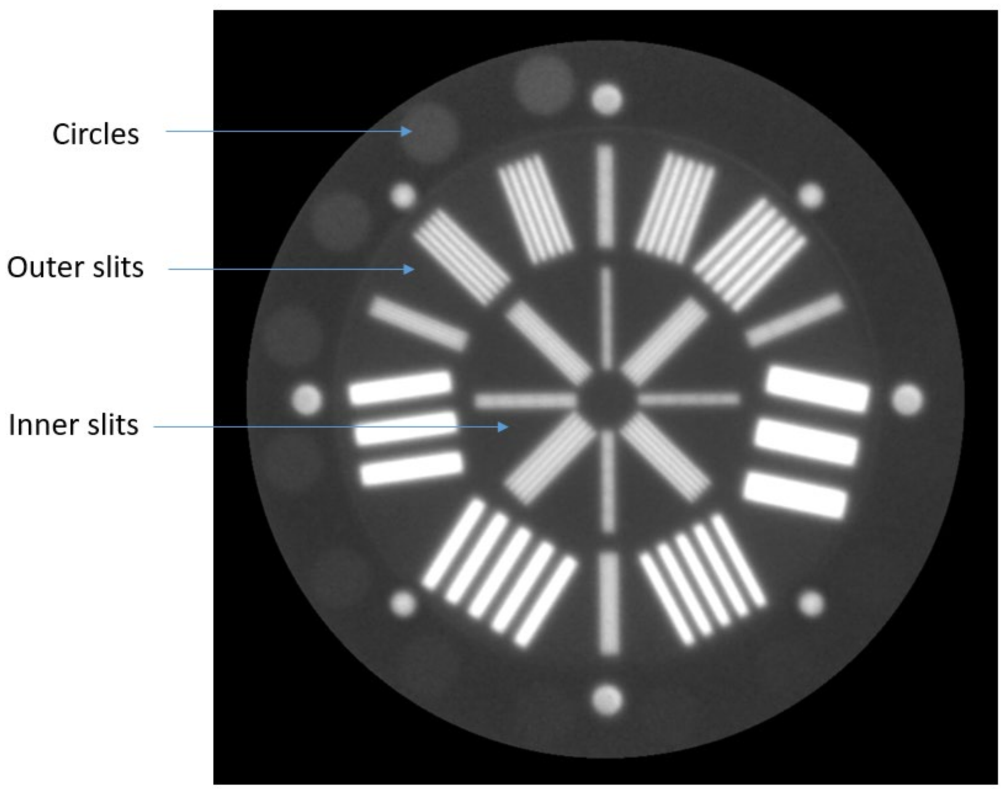

Figure 1 - DARHT radiograph of the KTO.

[1] All dimensions were transcribed from drawings 1DT-1032910-L00-00 and DRW-00775-00-R01_151129-1.

Methods

The two analysis methods described here assume the input data are fully pre-processed and aligned images of the KTO. Pre-processing was done using the standard DARHT `doall` IDL code, which performs bias subtraction, flat-fielding, de-starring, de-warping and magnification corrections. In the case of DARHT Axis 2 images, `doall` also performs image normalization and stitching. The pre-processed images are then aligned using optimization in the BIE code as shown in Figure 2.

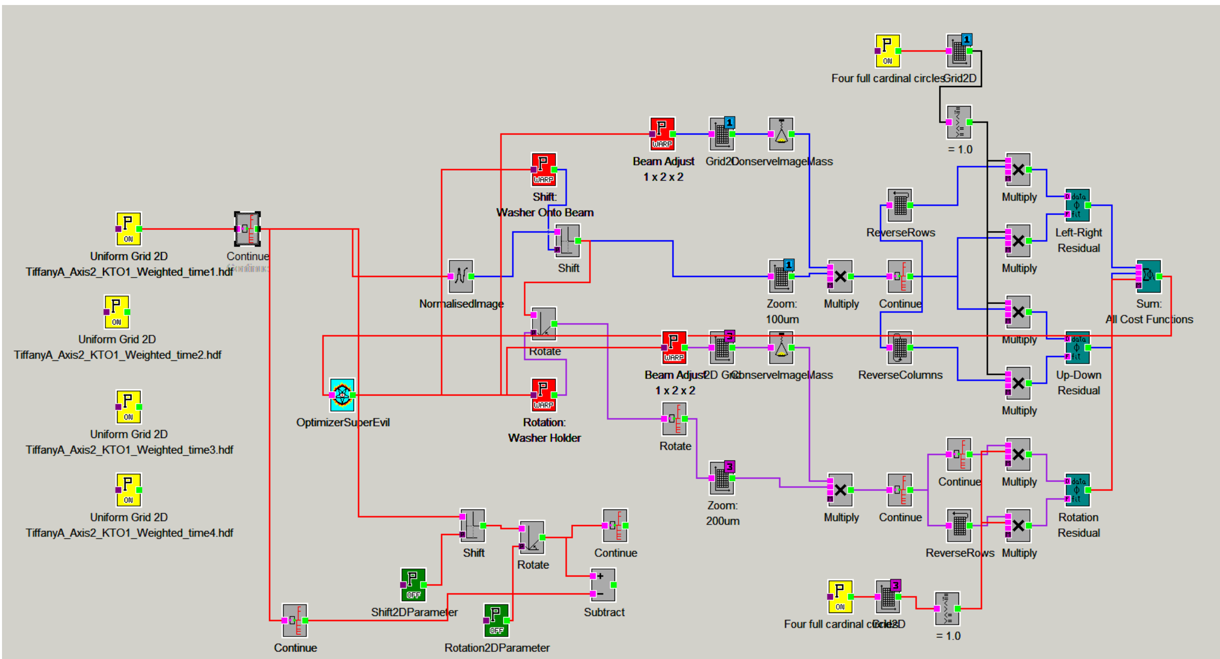

Figure 2 - KTO alignment canvas in BIE.

Alignment optimization was done by comparing flipped and rotated copies of a masked-out portion of the image. The fiducial regions for this analysis are the four through-holes at the top, bottom, left and right of the KTO. After alignment, the image is sliced to provide the salient regions for the analysis, as shown in Figure 3.

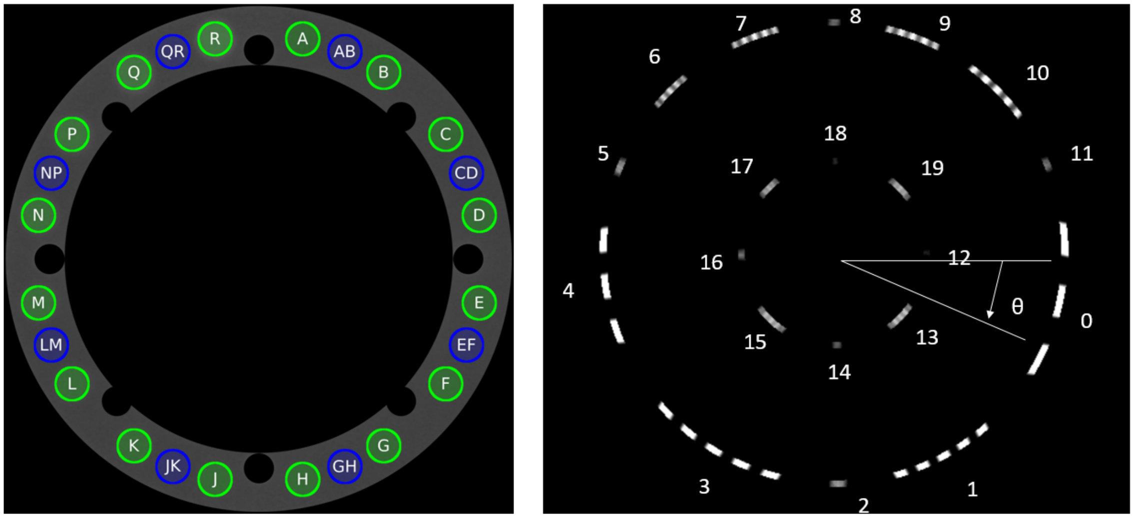

Figure 3 - Fully corrected image sections ready for analysis.

CNR calculation: The IDL code `kto_circle_cnr.pro` scans the circle image shown in the left panel in Figure 3 to find image pixels within 16 foreground and 8 background regions, all defined as 6 mm diameter circles, which is slightly smaller than the object feature diameter to avoid edge effects. The nearby through-hole bright spots must be avoided to get well-behaved data for which all pixels values are clustered in a single mode distribution well described by values of mean and standard deviation. Each foreground circle has a local background circle adjacent, and one background circle is shared by two foreground circles to avoid these hotspots (e.g. foreground circles A and B both use background circle AB). For example, the CNR calculation for circle A is as follows, where the pixel mean and standard deviations are calculated in the usual way:

$$CNR_A = \frac{\mu_A - \mu_{AB}}{\sqrt{\sigma_A^2 + \sigma_{AB}^2}}$$

CNR results are tabulated against the object feature depth in mm.

MTF calculation: The IDL code `kto_slit_mtf.pro` extracts a trace of the segmented image shown in the right panel in Figure 3 to make a single trace of pixel intensity versus azimuthal angle (see Figure 4). The orientation of the azimuthal angle θ is shown in Figure 3. Coarse regions are specified in θ within which all local maxima and minima are automatically found for a feature set. The median values of the set of maximum and minimum intensities are then used to calculate modulation following a published method [1]. The image modulation is related to intensity maxima and minima by the following relation, for a region in the image with constant spatial frequency.

$$M_{\text{image}} = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

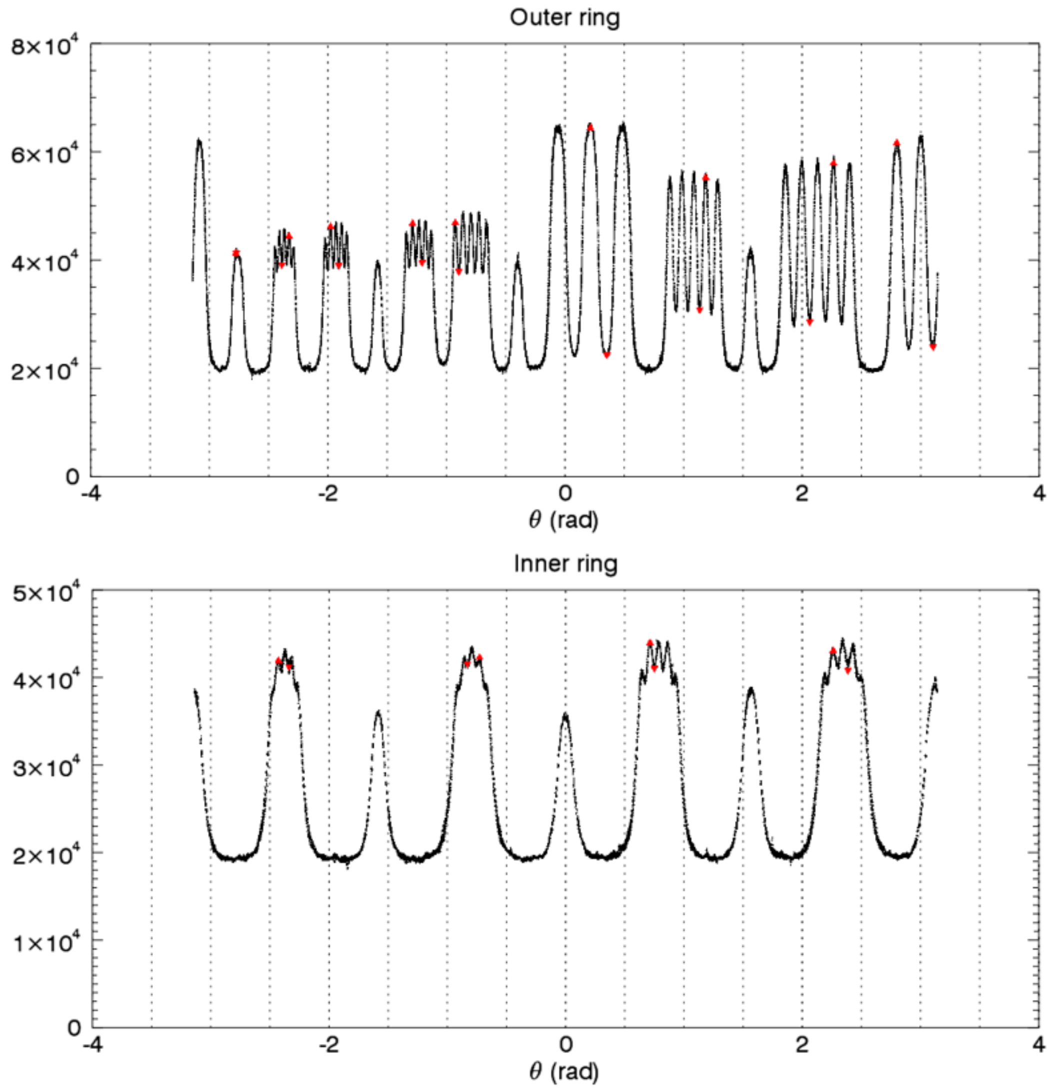

Figure 4 - Sample traces for MTF segmented image. Selected median local maxima and minima are marked by red triangles.

The object modulation is not unity in the case of penetrating x-rays. For this object, the modulation is constant and can be estimated by calculating the energy-integrated transmission fraction of the x-ray beam through the KTO. A straightforward way to accomplish this is to use the KTO image to compare the unobstructed transmission through one of the widest slits (a slit at the edge of the feature set should be used to avoid superposition of intensity with other slits as much as possible) with the adjacent dark region (see Figure 5).

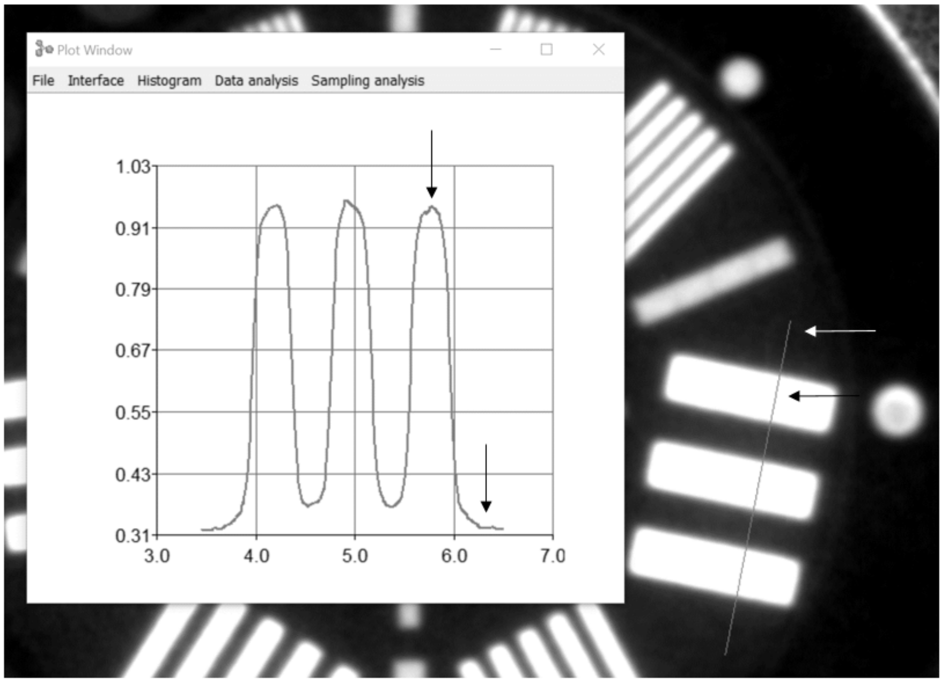

Figure 5 - Method of calculating object modulation with the KTO.

The object modulations calculated for Tiffany A images using this method are tabulated below.

DARHT Axis	M_{object}
A1	0.55
A2 Time 1	0.50
A2 Time 2	0.51
A2 Time 3	0.49
A2 Time 4	0.48

The modulation transfer is defined

$$MT \equiv M_{\text{image}}/M_{\text{object}}$$

The MTF is the modulation transfer as a function of spatial frequency, ξ, in line-pairs per millimeter. In the case of the KTO the object modulation in the slit region is constant, such that MTF is given by

$$MTF(\xi) \equiv M_{\text{image}}(\xi)/M_{\text{object}}$$

Results

MTF and CNR results are shown for Tiffany A shot in Figures 6 and 7. The MTF result shows that for this data set, A2 Time 2 gives the best modulation transfer from object to image, until a spatial frequency of around 0.7 mm^{-1}, beyond which A1 gives the highest MT. The CNR result shows that A2 Times 2, 3 and 4 have much better contrast to noise performance than A2 Time 1 and A1. MTF and CNR results presented in this way with KTO data can be used to compare DARHT radiography performance between different experiments.

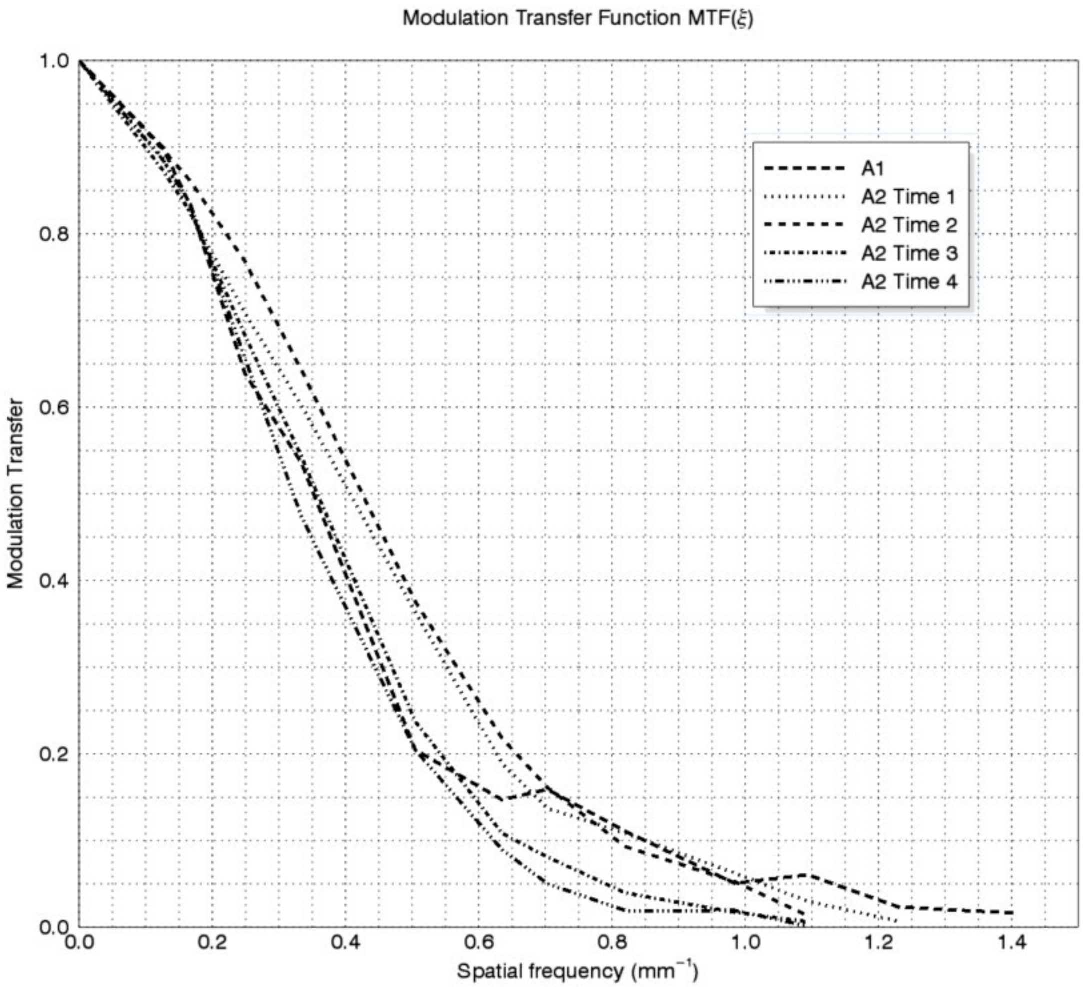

Figure 6 – MTF for all five Tiffany A images.

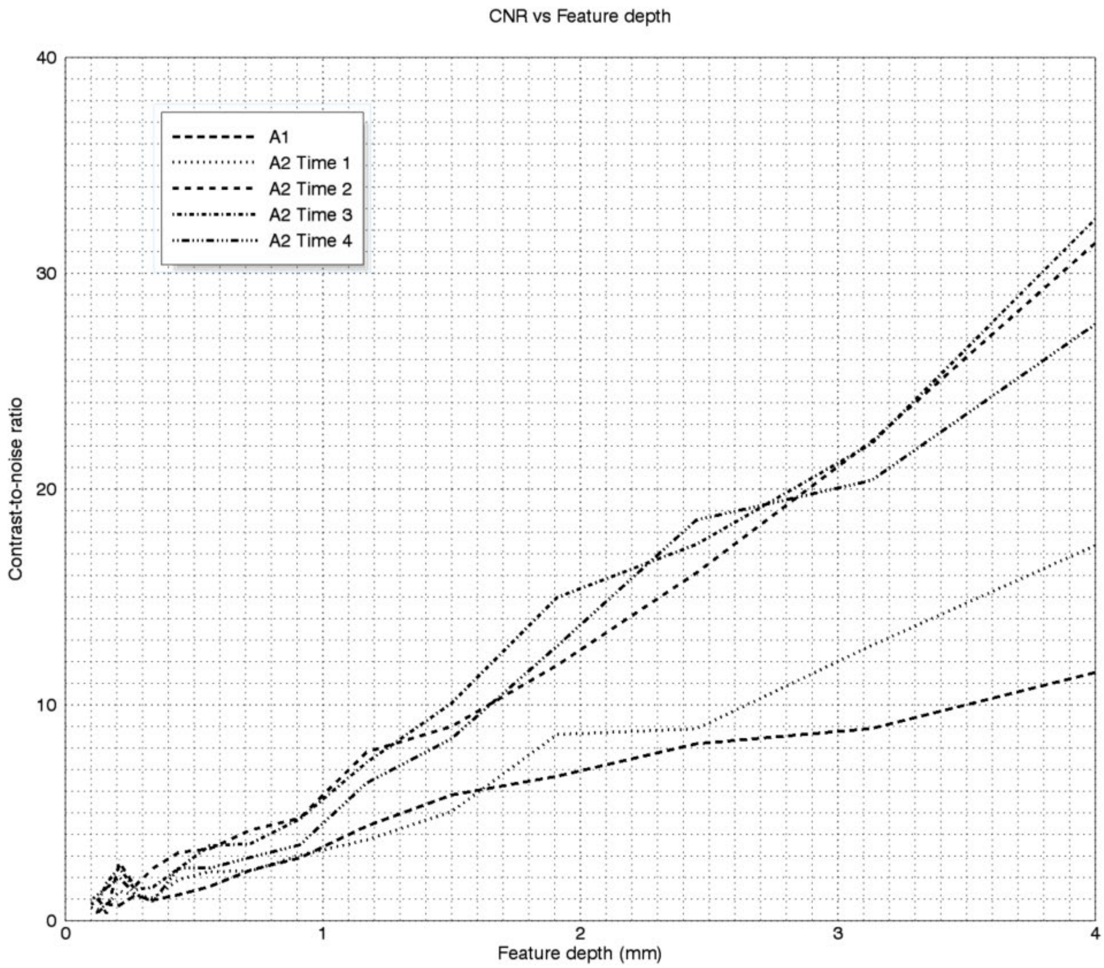

Figure 7 - CNR vs. feature depth for all five Tiffany A images.

References

[1] G.D. Boreman, *Modulation Transfer Function in Optical and Electro-optical Systems*, SPIE Press, 2001.